AMMONIA

Drinking Water Health Advisory
Office of Water
U.S. Environmental Protection Agency

I. INTRODUCTION

The Health Advisory (HA) Program, sponsored by the Office of Water (OW), provides information on the health effects, analytical methodology and treatment technology that would be useful in dealing with the contamination of drinking water. Health Advisories describe nonregulatory concentrations of drinking water contaminants at which adverse health effects would not be anticipated to occur over specific exposure durations. Health Advisories contain a margin of safety to protect sensitive members of the population.

Health Advisories serve as informal technical guidance to assist Federal, State and local officials responsible for protecting public health when emergency spills or contamination situations occur. They are not to be construed as legally enforceable Federal standards. The HAs are subject to change as new information becomes available.

Health Advisories are developed for One-day, Ten-day, Longer-term (approximately 7 years, or 10% of an individual's lifetime) and Lifetime exposures based on data describing noncarcinogenic end points of toxicity. For those substances that are known or probable human carcinogens, according to the Agency classification scheme (Group A or B), Lifetime Health Advisories are not recommended. The chemical concentration values for Group A or B carcinogens are correlated with carcinogenic risk estimates by employing a cancer potency (unit risk) value together with assumptions for lifelong exposure and the ingestion of water. The cancer unit risk is usually derived from a linearized multistage model with 95% upper confidence limits providing a low-dose estimate of cancer risk. This provides a low-dose estimate of cancer risk to humans that is considered unlikely to pose a carcinogenic risk in excess of the stated values. Excess cancer risk estimates may also be calculated using the one-hit, Weibull, logit or probit models. There is no current understanding of the biological mechanisms involved in cancer to suggest that any one of these models is able to predict risk more accurately than another. Because each model is based on differing assumptions, the estimates that are derived can differ by several orders of magnitude.

II. GENERAL INFORMATION AND PROPERTIES

Ammonia is a ubiquitous naturally occurring inorganic chemical. In aqueous solution, it exists in a number of forms that include the following: NH_3, NH_4OH, $NH_3.H_2O$ and NH_4^+. For purposes of this document, ammonia is used as a general term encompassing NH_3 and NH_4^+.

CAS No. 7664-41-7

Structural Formula

NH_3

Ammonia

Synonyms

- None.

Uses

- Ammonia is used in fertilizers, refrigeration systems and manufacturing processes (Windholz et al., 1983).

- Used in conjunction with chlorine to form chloramine which is used as drinking water disinfectant.

Properties (Campbell et al., 1958; Verschueren, 1977; Windholz et al., 1983)

Chemical Formula	NH_3
Molecular Weight	17.03
Physical State (25°C)	Liquid
Boiling Point	33.4°C
Melting Point	-77.7°C
Density (-33°C, 1 atm)	0.6818
Vapor Pressure (20°C)	8.5 atm
Specific Gravity	--
Water Solubility (20°C)	531 g/L
Log Octanol/Water Partition Coefficient (log K_{ow})	--
Taste Threshold	34 mg/L
Odor Threshold (air)	0.04 g/m^3
Conversion Factor	--

Occurrence

- Survey of total ammonia (NH_3 + NH^+_4) concentrations in surface waters indicate an average of 0.18 mg/L in most areas, and 0.5 mg/L in waters near large metropolitan areas (U.S. EPA, 1979). Levels in ground water are usually low, since ammonia is generally immobile in soil (Feth, 1966). Ammonia is effectively eliminated when drinking water is chlorinated.

- Ammonia is a negligible natural constituent of food, but ammonium compounds are added in small amounts (0.001 to 2%) to various foods as stabilizers, leavening agents, flavorings or for other purposes (FASEB, 1974).

Environmental Fate

- Ammonia is introduced into the environment through sewage effluents, fertilizer application, agricultural runoff, drainage from feedlots and through industrial discharge. Once present in an environment, ammonia participates in the constant fluxing of nitrogen levels and states of the nitrogen cycle. Processes related to this cycle are nitrogen fixation, nitrification, denitrification and ammonification. Ammonia is subject to assimilation by chemotrophic and phototropic organisms, or may be biologically oxidized (nitrification). Nonbiological means of moving ammonia within an environment include diffusion, dilution (in waters), volatilization and sorption to particles.

III. PHARMACOKINETICS

Absorption

- Ammonia is produced in humans in the stomach, duodenum, ileum, colon and feces at an estimated 4,200 mg/kg/day, with the colon and fecal content contributing about 73%. Of the total amount produced, 4,150 mg/kg/day is absorbed and 50 mg/kg/day is excreted (Summerskill and Wolpert, 1970).

- Conn (1972) administered 9 mg NH_4Cl/kg as uncoated tablets to 20 normal human subjects and 50 cirrhotic patients. Blood ammonia concentration peaked (mean, 140 ug NH_3/100 mL) at 15 minutes and returned to fasting levels (mean, 105 ug NH_3/100 mL) by 30 minutes in normal human subjects. In 50 patients with cirrhosis of the liver, however, blood ammonia levels increased from elevated fasting levels (mean, 155 ug NH_3/100 mL) to higher peak concentrations (mean, 370 ug NH_3/100 mL) at 15 minutes. This was followed by a slow decrease in ammonia levels, reflecting impaired hepatic urea synthesis.

- Castell and Moore (1971) studied ammonia absorption from the human gut by direct perfusion in four patients in whom surgical colon bypass procedures had been performed previously for chronic hepatic encephalopathy. Eight solutions at pH 5 (acetate buffer) and eight solutions at pH 9 (trihydroxyaminomethane buffer) with varying NH_3-N concentrations between 10 and 150 μg/mL were infused at 15 mL/min into a proximal colonic stoma for 20 minutes. In two patients, 12 infusions were also given at varying pH with both phosphate (pH 5, 6.6 and 8.2) and trihydroxyaminomethane buffer (pH 7, 8, 9). Ammonia absorption in the human colon showed a positive linear (or slightly curvilinear) relationship with intraluminal concentrations of ammonia up to 150 μg/mL. There was greater absorption of ammonia occurred consistently at all concen-trations, as the pH of the infused fluid was changed from 5 to 9.

Distribution

- In healthy individuals, ammonia that is absorbed following oral administration is mainly converted in the liver to urea; therefore, relatively small amounts reach systemic circulation (Summerskill and Wolpert, 1970). No other details were provided.

Metabolism

- Much of the ammonia absorbed in the gut is transformed to urea in the liver, while some is incorporated into tissue proteins (Richards et al., 1968, 1975; Summerskill and Wolpert, 1970). The transformation of ammonia into tissue protein varies inversely to the amount of protein consumed in the diet (Kies and Fox, 1978).

Excretion

- Excretion of ammonia following oral administration to humans is modified by protein intake. Richards et al. (1968, 1975) administered $^{15}NH_4Cl$ orally to healthy male volunteers fed a normal (70 g of protein in 24 hours) or protein-restricted diet (20 g of protein in 24 hours). The total dose of 9.2 to 17.2 mg NH_4Cl/kg was administered as five divided doses at 4-hour intervals. Within 7 days, approximately 70% of the ingested isotope was excreted in the urine and feces of the test group on the normal diet. In the protein-restricted diet group, the excretion value was approximately 35% of the ingested isotope. In uremic patients, excretion of the isotope was comparable to that of healthy, protein-restricted individuals.

IV. HEALTH EFFECTS

Humans

Short-term Exposure

- Ingestion of an ammonium hydroxide solution containing 2.4% ammonia resulted in the death of an adult male. Autopsy revealed a hemorrhagic esophago-gastro-duodeno-enteritis, with ammonia odor in the stomach contents (Klendshoj and Rejent, 1966).

Long-term Exposure

- No data were found in the available literature on the chronic toxicity to humans of ammonia following oral administration.

Animals

Short-term Exposure

- An acute oral LD_{50} of 350 mg/kg was reported in rats administered ammonia (Smyth et al., 1941).

Dermal/Ocular Effects

- No studies were found in the available literature on the dermal or ocular effects of ammonia by oral administration.

Long-term Exposure

- No studies were found in the available literature on the long-term effects of ammonia by oral administration.

Reproductive Effects

- No studies were found in the available literature on the reproductive effects of ammonia by oral administration.

Developmental Effects

- No studies were found in the available literature on the developmental effects of ammonia by oral administration.

Mutagenicity

- No studies were found in the available literature on the mutagenic effects of ammonia by oral administration.

Carcinogenicity

- No studies were found in the available literature on the carcinogenicity of ammonia by oral administration.

Organoleptic Consideration

- Campbell et al. (1958) determined the threshold concentration for ammonia in redistilled water based on the responses of 21 to 22 judges participating in "difference tests of the triangle type." At ammonia concentrations of 26, 52 and 105 mg/L, the percentages of correct identification by the judges were 61.9, 71.4 and 85.7, respectively. Defining the threshold concentration as the level at which correct identification is 50% greater than that expected by chance, the taste threshold of ammonia was determined to be 34 mg/L. Based on assumed water consumption of 2 L/day and average body weight of 70 kg, this dose corresponds to 0.97 mg/kg/day.

V. QUANTIFICATION OF TOXICOLOGICAL EFFECTS

Health Advisories (HAs) are generally determined for One-day, Ten-day, Longer-term (up to 7 years) and Lifetime exposures if adequate data are available that identify a sensitive noncarcinogenic end point of toxicity. The HAs for noncarcinogenic toxicants are derived using the following formula:

$$\frac{\text{(NOAEL or LOAEL) x (BW)}}{\text{(UF) (\_\_ L/day)}} = \text{\_\_ mg/L (\_\_ } \mu\text{g/L)}$$

where:

NOAEL or LOAEL = No- or Lowest-Observed-Adverse-Effect Level (in mg/kg bw/day).

BW = assumed body weight of a child (10 kg) or an adult (70 kg).

UF = uncertainty factor, (10, 100, 1,000 or 10,000P, in accordance with EPA or NAS/OW guidelines.

__ L/day = assumed daily water consumption of a child (1 L/day) or an adult (2 L/day).

One-day Health Advisory

No data were found in the available literature that were suitable to use in the determination of the One-day Health Advisory (HA).

Ten-day Health Advisory

No data were found in the available literature that were suitable to use in the determination of the Ten-day HA.

Longer-term Health Advisory

No data were found in the available literature that were suitable to use in the determination of the Longer-term HA.

Lifetime Health Advisory

The Lifetime HA represents that portion of an individual's total exposure that is attributed to drinking water and is considered protective of noncarcinogenic adverse health effects over a lifetime exposure. The Lifetime HA is derived in a three-step process. Step 1 determines the Reference Dose (RfD), formerly called the Acceptable Daily Intake (ADI). The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious health effects during a lifetime, and is derived from the NOAEL (or LOAEL), identified from a chronic (or subchronic) study, divided by an uncertainty factor(s). From the RfD, a Drinking Water Equivalent Level (DWEL) can be determined (Step 2). A DWEL is a medium-specific (i.e., drinking water) lifetime exposure level, assuming 100% exposure from that medium, at which adverse, noncarcinogenic health effects would not be expected to occur. The DWEL is derived from the multiplication of the RfD by the assumed body weight of an adult and divided by the assumed daily water consumption of an adult. The Lifetime HA in drinking water alone is determined in Step 3 by factoring in other sources of exposure, the relative source contribution (RSC). The RSC from drinking water is based on actual exposure data or, if data are not available, a value of 20% is assumed.

If the contaminant is classified as a known, probable, or possible human carcinogen, according to the Agency's classification scheme of carcinogenic potential (U.S. EPA, 1986), then caution must be exercised in making a decision on how to deal with possible lifetime exposure to this substance. For human (A) or probable (B) human carcinogens, a Lifetime HA is not recommended. For possible (C) human carcinogens, an additional 10-fold safety factor is used in the calculation of the Lifetime HA. The risk manager must balance this assessment of carcinogenic potential and the quality of the data against the likelihood of occurrence and significance of health effects related to noncarcinogenic endpoints of toxicity. To assist the risk manager in this process, drinking water concentrations associated with estimated excess lifetime cancer risks over the range of 1 in 10,000 to 1 in 1,000,000 for the

70-kg adult drinking 2 L of water/day are provided in the Evaluation of Carcinogenic Potential section.

There are no suitable studies available in the literature for the derivation of a Lifetime HA for ammonia. Ammonia is produced in humans in the stomach, duodenum, ileum, colon and feces at an estimated 4,200 mg/kg/day, with the colon and fecal content contributing about 73%. However, ingestion of 2.4% ammonium hydroxide solution (24 g/L) has resulted in the death of an adult male. Autopsy revealed a hemorrhagic esophago-gastro-duodeno-enteritis, with ammonia odor in the stomach contents. It appears that the observed toxic effects were due to the local effects rather than the systemic effects and ammonia at low concentration, per se, is not very toxic. Therefore, it is recommended that the taste and odor level of 34 mg/L be used as a guide for the Lifetime HA.

Evaluation of Carcinogenic Potential

- The International Agency for Research on Cancer (IARC) has not evaluated the carcinogenic potential of ammonia.

- The weight of evidence that ammonia is a carcinogen has not yet been evaluated by the EPA. Applying the criteria described in EPA's guidelines for assessment of carcinogenic risk (U.S. EPA, 1986), ammonia may be placed in Group D: not classifiable. This category is for agents with inadequate animal evidence of carcinogenicity.

VI. OTHER CRITERIA, GUIDANCE AND STANDARDS

- The American Conference of Governmental Industrial Hygienists (ACGIH) suggests a Threshold Limit Value (TLV) of 25 ppm (18 mg/m^3) as a Time-Weighted Average (TWA) for an 8-hour work day (ACGIH, 1987-88). A Short-Term Exposure Limit (STEL) of 35 ppm (27 mg/m^3) has been suggested.

VII. ANALYTICAL METHODS

- Ammonia is one of the classical water quality monitoring parameters, the concentration of which is important in eutrophication problems. It has been monitored at low levels in ambient waters for a long time. EPA Methods 350.1, 350.2, 350.3 are available for the determination of ammonia. Method 350.3 is a specific ion electrode method, the others are colorimetric/titrimetric/potentiometric. Method 350.1 is an automated procedure. The type of interferences from other nitrogen compounds such as amines is well documented. The detection limits available by these methods ranges from 10 to 50 µgm/L (U.S. EPA, 1979).

VIII. TREATMENT TECHNOLOGIES

- Available data indicate that aeration, reverse osmosis (RO), combination lime softening and RO, and adsorption by natural zeolite significantly reduce ammonia concentrations in the drinking water supply.

- Powers et al. (1987) developed a mathematical model to examine the operating parameters that might affect the ammonia removal rate by a batch aerated-bubble stripping process. The model requires the liquid tank volume, lime dosing for pH adjustment, steam flow rate dosing and air flow rate to produce an ammonia concentration profile at a given initial ammonia concentration. Using this model, the optimum operating conditions for this stripper are: air flow rate of 110 cfm and a maximum steam flow rate of 700 lb/hr., with a required stripping time of 14 hours. This model predicted a reduction of the ammonia concentration by 96% from a concentration of 4,000 mg/L as ammonia-nitrogen.

- Shpirt (1981) using a bench-scale apparatus and a mathematical model demonstrated that diffused aeration is a feasible technology for ammonia reduction. The apparatus consisted of two different types, one giving coarse bubbles (a section of glass pipe), the other giving fine bubbles (diffuser stone). The initial concentration of ammonium chloride was in the range of 50 to 100 mg N/L, and the pH was adjusted to 11.5 with a 40% by weight solution of sodium hydroxide. A series of experiments were performed at different column heights and air flow rates. The results showed that the overall coefficient of mass transfer increases with increasing air flow rate and decreases with increasing depth of diffuser submersion. Furthermore, fine bubble aeration had twice the efficiency as coarse bubble aeration in removing ammonia.

- Houel et al. (1979) studied and reported the removal of ammonia by aeration in a counter current stripping tower with a cross section of 23 inches by 18 inches and a total packing depth of 13.83 feet. Air flow rate was maintained at 1,250 cfm and the water flow rate was maintained at 5 gpm. Two types of packing materials were tested. Type A packing was a 0.5 inches thick "egg crate" type polystyrene sheet, and Type B packing was made from polyvinyl chloride (PVC) sheets. Ammonia was present at an influent concentration of 80 mg/L. Type A packing removed an average of 88% of the ammonia, while Type B packing removed an average of 53%.

- Benneworth and Morris (1972) studied the factors affecting ammonia removal by aeration. They concluded that the rate of ammonia desorption increases rapidly as the pH rises from 7 to 10.5 and above pH 10.5 no significant improvement can be obtained. The air requirements are governed by the value of the solubility coefficient. A theoretical minimum air to liquid ratio was calculated to be 1,400 for 90% ammonia removal.

- O'Farrell and Bishop (1976) described a pilot plant which used aeration to remove ammonia from a second-stage clarifier effluent at pH 10.5. The tower was operated at a loading rate of a 2 gpm/sq. ft. at an air to water ratio of 2,600. In general, this system, operated at 45°F, removed 56% of the ammonia from an initial concentration of 9.5 mg/L measured as ammonia-nitrogen.

- Terril and Neufeld (1983) reported data from a reverse osmosis unit used to treat blast-furnace scrubber effluent. The ammonia concentration in the influent was 128 mg/L. The RO unit contained a cellulose acetate membrane (CA) and was operated at pressures of 350 to 450 psig and a water recovery rate of 70 to 80%. This system achieved 93% reduction in ammonia levels.

- Argo (1984) reported the performance of a lime softening/RO plant for water reclamation. Potable water was reclaimed from the unchlorinated effluent of an activated sludge wastewater treatment plant by lime softening, reacidification and RO. Two 5,000 gpd RO pilot plants consisting of tubular aromatic polyamide membranes in a 2-1 array configuration were operated in parallel at a flux rate of 7.14 gpd/sq ft and at an applied pressure of 250 psi. This system reduced ammonia concentration by more than 95% from an average influent concentration of 15 mg/L.

- Blanchard et al. (1984) studied removal of ammonia in a pilot plant using natural zeolite clinoptilolite, as an ion exchanger. The pilot plant consisted of two columns operated in series, each 8 inches in diameter and packed with 40 inches of zeolite, and a flow rate of 12 bed volumes (BV) per hour, for a total BV = 1.16 cu. ft. Ammonia breakthrough occurred after 480 BV at an influent concentration of 2.63 mg/L. Breakthrough concentration was set at 50 μg/L, after which the zeolite was regenerated with NaCl at a flow rate of 10 BV/hr.

- No data were found for the removal of ammonia from drinking water by activated carbon adsorption. However, ammonia may not be amenable to removal by activated carbon adsorption due to its very high solubility and low molecular weight.

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